Quarterly Progress Report, August 1994 - October 1994
ONR Contract Number N00014-93-1-1235
Drew McDermott, PI
Yale University Department of Computer Science

Our work on perception-based planning and execution continues:

- During this period, we made substantial progress on visual tracking for our mobile robotic system, and upgraded our tracking system framework.

  We have begun construction of a navigation system for our mobile robot based entirely on visual tracking. During this period, we developed SSD-based tracking systems, and used those systems to demonstrate robot motion along a pre-defined path. This demonstration included automated selection of features to track and tracking of features in realtime as the robot moved. We are currently working on extending the system capabilities, optimizing the tracking functions, and "robustifying" the tracking methods.

  We have extended our tracking system framework in a number of ways. Earlier versions of the tracking system required tracking networks to be strictly heirarchical. This made it difficult to share features among different system components requiring visual feedback. The new system eases this heirarchical requirement, making it possible to have more fully interconnected networks. We have also developed a typing system for trackers, making it possible to define generical geometric and logical constructions independent of the implementation of the tracking components. These modifications have substantially simplified the construction of visual servoing systems.

- We continue to build a library of plans and transformations for our work on sensor-guided planning. The current work focusses on getting the necessary body of planning knowledge to carry out our main experiments. For this purpose we are implementing failure models for additional kinds of execution failures and plan revision rules indexed by these failures.

  During this period we

  - developed concepts for the specification of deadlines and temporal constraints for declarative goals. RPL will be extended to allow for the following kinds of declarative goals:
    * **(ACHIEVE g BY deadline)**
    * **(MAINTAIN s OVER interval)**
    * **(STABILIZE s UNTIL ti)**
  - compared different approaches for updating the world model of the robot. The question is how to integrate information returned by sensing routines into the current world model such that the world model is consistent with the robot's perceptions and actions and such that most observations are integrated in the world model.
  - implemented revision rules for perceptual confusion
  - implemented revision rules for task interferences
  - implemented revision rules for deadlines

- In the course of trying to develop a pedagogical framework for explaining classical planners, we discovered a novel technique for managing means-ends planning. "Means-ends planning" is the process of adding to a plan feasible actions that achieve part of the overall goal. There is an obvious problem here, which is what do we do if no feasible action achieves part of the goal? The standard answer is to make subgoals part of the search state, and provide for two kinds of operator: adding actions, and sprouting subgoals. The alternative we explored was an algorithm that finds at one go all actions that are feasible and relevant to a sub-sub-...-subgoal of the overall goal.

This algorithm constructs a *greedy regression-match graph,* which keeps track of both (a) the best match between each conjunctive subgoal and the current situation, and (b) all actions that can achieve a goal conjunct. Preliminary results indicate that this graph provides a good indicator of the best action to take first in pursuit of a goal, and how many actions will remain after that.

Publications

Hemant Tagare and Drew McDermott. Model-Based Edge Selection for 2-D Object Recognition. Yale Computer Science Department Technical Report 1044. Submitted to CVGIP.

G. Grunwald, Greg Hager, and G. Hirzinger . Feature-Based Visual Servoing and its Application to Telerobotics (with and). *Proceedings of the 1994 IEEE/RSJ International Conference on Intelligent Robots and Systems,* pages 164–171. IEEE Computer Society Press, Sept. 1994.

C.P. Lu, E. J. Mjolsness, and Greg Hager. Online Computation of Exterior Orientation with Application to Hand-Eye Calibration . Submitted to *Mathematical and Computer Modeling,* Aug., 1994.

Greg Hager and Kentaro Toyama. Flexible Tools for Hand-Eye Coordination (Video Tape), submitted to ICRA '95 Video proceedings, Oct. 1995.

Activities:

Become co-editor of a special section of IEEE Trans. Robotics and Automation on "vision-based motion control."

Personnel Support:

- *Professors (summer):* Drew McDermott and Greg Hager
- *Graduate Students (full time):* Michael Beetz, Aage Bendiksen, Kentaro Toyama
- *Post-doc (half-time):* Hemant Tagare
- *Secretary (half-time):* Paula Murano

Expenditures:

The accompanying table shows the figures for expenditures to date, including amounts committed but not actually spent.

Overall Status and Plans:

We are pushing toward integration of our robot-map maintenance work with our visual-feature-tracking work.

We are (finally) beginning a series of experiments to test the real-time efficacy of our transformational planner.

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
NON-LADDER ACAD $ RES APPTS	44,765	2,619.99	12,413.36	15,033.35	29,731.65
FACULTY SUMMER COMP	55,084	.00	38,000.00	38,000.00	17,084.00
MANAGERIAL & PROFESSIONAL	9,905	6,069.28	14,387.69	20,456.97	-10,551.97
STUDENT ASST.	21,310	10,447.98	30,800.00	41,247.98	-19,937.98
EMP. BENEFITS	36,208	2,854.78	20,289.67	23,144.45	13,063.55
D/P SUPPLIES	0	-220.00	220.00	.00	.00
MINOR EQUIPMENT	0	-249.95	3.00	-246.95	246.95
D/P SVS.	3,076	6,000.00	12,754.00	18,745.00	-15,673.00
D/P SOFTWARE PURCHASES	0		139.00	139.00	-139.00
FREIGHT & TRANSPORTATION	0	63.50	135.73	199.23	-199.23
PHOTOCOPYING	795	581.90	1,199.64	1,781.54	-986.54

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
PRINTING-PUBLICATIONS	0		1,000.00	1,000.00	-1,000.00
MISC. SERVICES	0		36.00	36.00	-36.00
TRAVEL (DOMESTIC)	0	477.08	5,027.56	5,504.64	-5,504.64
OFFICE SUPPLIES	489		86.96	86.96	402.04
TUITION REMISSION	2,839	7,633.31	21,520.00	29,153.31	-26,314.31
PERIODICALS, BOOKS	0		375.35	375.35	-375.35
POSTAGE	0	56.72	354.11	410.83	-410.83
HEALTH INS.	0	1,508.00	1,476.00	2,984.00	-2,984.00
TELEPHONE TOLLS	495	128.38	156.28	284.66	210.34
DATA PROC. EQUIPMENT	15,007	986.00	7,446.20	8,432.20	6,574.80
INDIRECT (OVERHEAD 64.0%)	110,162	19,416.09	88,866.48	108,282.57	1,879.43
TOTAL:	300,135	58,373.06	256,687.03	315,060.09	-14,925.09
		ACCOUNT WILL BE OVERDRAWN:			-14,925.09

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